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Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

Mining Research Laboratories
Laboratoires de recherche minière

Canada/NB MDA Project on Mine-shaft Rope Testing;

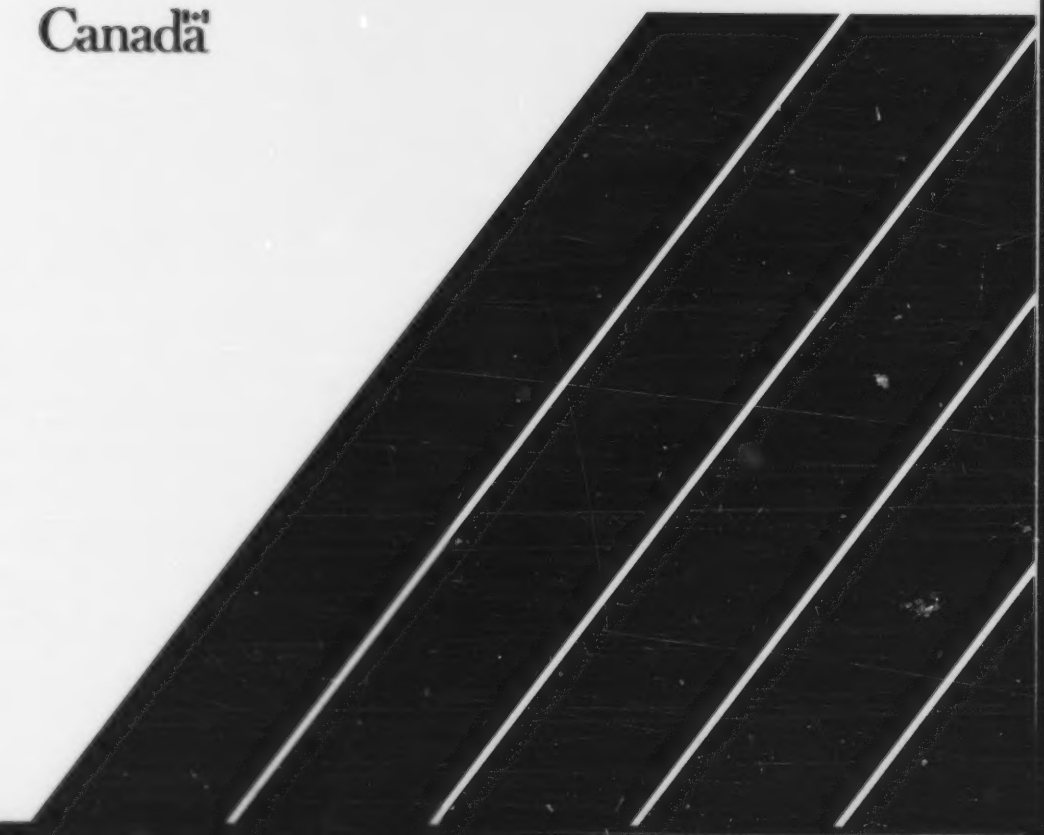
$1\frac{11}{16}$ in., 33×7, NR ropes with artificial defects (our ropes 'C' & 'D')

L.B. Geller, G. Rousseau, and D. Poffenroth

MRL 91-073 (TR)

July, 1991

Canada



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CANADA/NB MDA PROJECT ON MINE-SHAFT ROPE TESTING; $1\frac{11}{16}$ in., 33×7, NR ROPES WITH ARTIFICIAL DEFECTS (OUR ROPES 'C' AND 'D')

by

L.B. Geller*, G. Rousseau**, and D. Poffenroth†

ABSTRACT

In response to requests by both the mining industry and the mine regulatory authorities, CANMET undertook a project in 1986 to comparatively evaluate, on a properly controlled experimental basis, the performance of a range of commercially available electro-magnetic (EM) wire-rope test instruments, including Canadian, American, and German testers. The project was unprecedented in its scope. It included both in-house and contracted work phases. The contracted work was funded from Canada/New Brunswick Mineral Development Agreement (MDA) sources. The latter covered both in-situ and shop-floor testing, on rope-sizes and constructions that are representative of the full range used in Canadian mines.

Test results were reported in an extensive series of referenced reports. The present report is the last one of this series. In it the authors analyse the results obtained non-destructively on two specially designed and manufactured $1\frac{11}{16}$ in. diameter, 33×7, spin-resistant/non-rotating (NR‡) tail-ropes (T.R.) with artificial defects. These ropes were only examined reel-to-reel.

The ropes were tested with the Canadian Magnograph and with the American LMA-250 instruments. The results are of special interest because they were obtained with the type of rope-anomalies that are, in practice, difficult to detect with EM type rope-testers.

The operators did not submit strength-loss (LBS) estimates.

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‡: it should be noted that even though the 'non-rotating' (NR) ropes are spin-resistant, they will rotate somewhat under certain conditions.

Keywords: New Brunswick; Mineral Development Agreement; Wire-ropes; Non-destructive-testing; Tail-ropes; Spin-resistant/Non-rotating ropes; Electro-magnetic instruments

Projet EEM Canada/NB sur l'essai de câbles de puits de mine;
Câbles AG 33×7 de 1 11/16 po, avec défauts artificiels
(Nos câbles 'C' et 'D')

par

L.B. Geller*, G. Rousseau**, et D. Poffenroth†

RÉSUMÉ

En réponse à des demandes tant de l'industrie minière que des organismes de réglementation des mines, CANMET a entrepris en 1986 un projet visant à évaluer comparativement, dans des conditions expérimentales contrôlées, le rendement d'une gamme d'instruments électromagnétiques (ÉM) d'essai des câbles métalliques, disponibles dans le commerce, y compris des instruments canadiens, américains et allemands. Le projet était d'une envergure inédite. Il a nécessité des travaux tant internes quá contrat. Les travaux à contrat ont été parraineés dans le cadre de l'Entente sur l'exploitation des minéraux (EEM) Canada/Nouveau-Brunswick. Ces derniers ont consisté en des essais sur le terrain et en atelier de câbles de tailles et de constructions représentatives de la gamme complète des câbles utilisés dans les mines canadiennes.

Les resultats des essais ont été colligés dans une imposante série de rapports. Le présent rapport, qui en constitue le dernier maillon, les liste comme références. Les auteurs y analysent les résultats d'essais non destructifs de deux câbles d'équilibre (CE) 33×7 antigiratoires (AG)‡ et résistant au torsion, de $1\frac{11}{16}$ po de diamètre, avec défauts artificiels, de conception et de construction spéciales. Ces câbles n'ont été vérifiés que d'une bobine à l'autre.

Les câbles ont été vérifiés à l'aide du Magnograph canadien et du LMA-250 américain. Les résultats sont particulièrement intéressants puis qu'ils furent obtenus avec des anomalies de câbles difficiles à détecter, en pratique, avec les instruments de type ÉM.

Les opérateurs n'ont pas fourni d'estimés de perte de capacité portante.

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‡: à noter que même si les câbles 'antigiratoires' (AG) résistent à la torsion, ils tournent un peu sur eux-mêmes dans certaines conditions.

Mots clés: câble métallique; essai non destructif; instrument électromagnétique; câble d'équilibre; câble antigiratoire résistant à la torsion; Nouveau-Brunswick; Entente sur l'exploitation des minéraux.

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BACKGROUND

The results described in this report constitute an integral part of the contracted phase of CANMET's project, undertaken in response to requests by both the mining industry and the mine regulatory authorities. The project was initiated in 1986. Contracted work commenced in July, 1988. The basic project objectives specified that the continuing rope failures, or near failures — occurring despite mandatory wire-rope examinations with electro-magnetic (EM) instruments at regular intervals — be examined, documented, analysed, and the reasons for these occurrences clarified. This is the first time a project of this scope and depth has been undertaken, anywhere.

CANMET's work included both in-house and contracted work phases. The in-house phase resulted in a range of conclusions and recommendations, reported elsewhere (references 1 through 6). We are now in the process of reporting the results obtained in the course of the contracted project-phase. It included an extensive series of both in-situ and shop-floor tests. The first eighteen reports to describe this project phase were prepared in the period February, 1990, through June, 1991 (references 7 through 24). The present report concludes this series of CANMET reports.

ROPE DETAILS

The specially designed and manufactured test-ropes, involved in the work we describe in this report (designated as our test-ropes 'C' and 'D') are of $1\frac{11}{16}$ in. nominal diameter, 33×7, NR**, fibre-core construction, with a nominal total metallic cross sectional area (A) of 1.21992 in^2, and a lay-length of $11\frac{3}{8}$ in. Each of the 33 strands contains seven 0.082 in. diameter wires with a metallic cross-sectional-area of some 0.005281 in^2 (representing some 0.43% of A).

It may be noted that standard NR rope constructions are of a 34×7 design, with strands in neighbouring rope layers laid in opposing directions, so as to counter the rope's rotation tendencies. In our particular case a 33×7 NR construction was used, due to an administrative oversight. A schematic of the standard rope construction, complete with the artificial anomalies, is shown in Fig. 1. As indicated, we introduced these anomalies by flattening the crown wires of strands in the middle and inner rope

**: it should be noted that even though the 'non-rotating' (NR) ropes are spin-resistant, they will rotate somewhat under certain conditions

layers as they surfaced, once along their $11\frac{3}{8}$ in. lay-length. This was done to simulate the damage suffered in operational use by these NR ropes at their 'cross-over' points, the latter being the points at which the wires between adjacent strands make contact.

We assumed that the sketched conditions in Fig. 1 are a fair representation of the average conditions along those 6-ft rope-sections that contain artificial defects at the 'cross-over' points. In other words we postulated that the density of the magnetic flux-flow in the circuit encompassed by the sensor-heads' North and South pole-pieces is governed by the sketched cross-sectional area.

The artificial anomalies were introduced along the 6-ft rope lengths of the middle and inner rope layers. First the chosen sections were delineated by paint. Then the crown-wires were flattened at the appropriate 'cross-over' points with a hand-held grinding wheel. Along one such 6-ft section (designated as length 'α') some 40% of the 0.082 in. wire-diameter was removed; along another 6-ft section (designated as length 'β') some 25% of the 0.082 in. wire-diameter was removed; while along section 'γ' some 10% of the original 0.082 in. wire-diameter was ground off.

The 500-ft long test-rope consisted of two equal 250-ft rope-lengths. One of these was designated as test-rope 'C', and the other as test-rope 'D'. A 2 in. section of seizing wire wound around the outside of the 500-ft rope at its centre divided 'C' from 'D'. The construction of rope 'C', in the order encountered during the actual test-runs, was as follows: (a) 170-ft at the overall rope-end, without artificial anomalies, (b) length 'α', (c) 6-ft without artificial anomalies, (d) length 'β', (e) 6-ft without artificial anomalies, (f) length 'γ', and (f) 50-ft without artificial anomalies. Now followed the seizing-wire-wound central section of the 500-ft rope, and then the 250-ft rope-length designated as test rope 'D'. Its construction was exactly the same as that of rope 'C'. Consequently, it consisted of (as encoutered during the actual test-run): (a) 170-ft with no anomalies at the centre of the overall (500-ft) rope-length (i.e., adjacent to the final 50-ft of rope 'C'), (b) length 'α', (c) 6-ft without artificial anomalies, (d) length 'β', (e) 6-ft without artificial anomalies, (f) length 'γ', and (f) 50-ft without artificial anomalies.

The only difference between ropes 'C' and 'D' was that we taped several 'calibration' wires to the final 50-ft rope-end of rope 'D' (i.e., to the section without other artificial anomalies). We designated the latter rope-sections as lengths 'δ' and 'ϵ' on the LMA chart-traces of the EM instruments. Along 'δ' we had placed, in a single rope-groove, two approximately 3-ft long $\times$ 0.080 in. diameter wires, with a 5 mm gap (marked 'X' on the LMA charts) between the ends of the two. Along 'ϵ' there were three parallel 3-ft lengths of these wires, one each in an adjacent rope-groove, with the ends of these wires kept as congruent as possible.

In Fig. 2 we reproduce photographs of the above detailed rope preparation process, from painting of the 6-ft segments, through grinding of the crown-wire anomalies, to closing of the strands. In Figures 2l through 2n we reproduce close-up views of the 6-ft long rope-sections with the artificial 'cross-over' point anomalies. These pictures illustrate the helical distribution of the anomalies; a distribution attempting to simulate the wear at the putative 'cross-over' points.

SHOP-FLOOR TEST RESULTS — AS REPORTED AND REVIEWED

General procedure

The shop-floor tests were undertaken, reel-to-reel, with a Magnograph and an LMA-250 instrument. The operators — from a Canadian service company, and from an American government agency — did not know about each other's results before these were submitted to us. All details of the testing process were described, and illustrated, elsewhere (7).

The LMA-250 Data

The LMA-250 data were obtained on 1990 03 06*. A copy of the strip-chart obtained on rope 'C' is reproduced in Fig. 3. We added to the chart: (a) the 100% reference level, (b) the location and designation of the characteristic rope sections, (c) the major %LMA chart-readings, (d) some of the travel-distance readings along the chart-edge, and (e) the direction of testing. Moreover, we added match-marks (e.g., ref. 'A', ref. 'B', etc.) since we were unable to reproduce the entire chart in a single length.

A copy of the strip-chart obtained on rope 'D' is reproduced in Fig. 4. We added the same markings to this chart, as to the one obtained for rope 'C' (Fig. 3).

Our comments on the results are contained in the 'Analysis of Test Results' section of this report.

The Magnograph Data

The Magnograph data were also obtained on 1990 03 06. A copy of the strip-chart obtained on rope 'C' is reproduced in Fig. 5. In Fig. 5a the sensitivity setting is 1.0% LMA per major chart division. In Fig. 5b we digitized the data stored on magnetic tape

*: dates are given in this order: year, month, day

and reproduced them at 0.5% LMA per major chart-division, in order to be consistent with the sensitivity setting used for the LMA-250 chart (Fig. 3).

As in case of the LMA-250 charts, we added to Figures 5a and 5b: (a) the 100% reference level, (b) the location and designation of the characteristic rope sections, (c) the major %LMA chart-readings, (d) some of the travel-distance readings along the chart-edge, and (e) the direction of testing. Moreover, we also added match-marks (e.g., ref. 'A', ref. 'B', etc.) since we were unable to reproduce the entire chart in a single length.

A copy of the strip-chart obtained on rope 'D' is reproduced in Fig. 6. In Fig. 6a the sensitivity setting is 1.0% LMA per major chart division. In Fig. 6b we digitized the data stored on magnetic tape and reproduced them at 0.5% LMA per major chart-division, in order to be consistent with the sensitivity setting used for the LMA-250 chart (Fig. 4). We added the same additional markings to this chart, as to the one obtained for rope 'C' (Fig. 5).

Our comments on the results are contained in the 'Analysis of Test Results' section of this report.

DESTRUCTIVE TESTING

The project-plans did not include destructive testing of the specially designed test-ropes with artificial defects, either of the $1\frac{3}{4}$ in. diameter ones with flattened strands described elsewhere (7), or of the $1\frac{11}{16}$ in. diameter rotation resistant ones described in this report.

ANALYSIS OF TEST RESULTS

The principal purpose for constructing, and testing, ropes 'C' and 'D' was to determine whether it was possible, and if so how difficult it was, to detect deterioration of the NR rope constructions at their 'cross-over' points.

While we could clearly detect the existence of the artificially introduced anomalies along the rope sections 'α', 'β', and 'γ', we question whether this would, in fact, have been so under normal test conditions as well. The question arises because, in the latter case: (a) the anomalies would not, necessarily, have been so evenly distributed over a 6-ft rope length, i.e., over a length well in excess of the EM instruments' sensor-head lengths, (b) the chart sensitivities would not, necessarily, have been set at the appropriate levels

for detecting such relatively minor faults, (c) it is always much easier to detect anomalies one is expecting to find, than ones whose presence can not be predicted. Moreover, under operating conditions the metal-loss at the 'cross-over' points along the rope is, presumably, less than — or at most equal to — a 10% diameter reduction. This amount would, most probably, not be noticeable on the LMA and LF chart-traces. As pointed out, hereunder, even our least severe artificial diameter reductions (along rope-sections 'γ') — barely noticeable, as is — were, most likely, in actual fact well in excess of the above assumed 10% value.

All the same we believe that the results described in this report will assist operators in locating 'cross-over' point damage in NR ropes, by demonstrating the instrument settings required to detect them, and by illustrating the likely combination of LF and LMA chart-trace perturbations that will result.

As expected, the presence of the 'calibration' wires could be detected with no trouble at all, and the level of their perturbation read accurately. Unfortunately, we were unable to be equally confident about the accuracy of the LMA chart-readings at the cross-over point anomalies. Our relevant calculations were the following:

(1) At the 'calibration' wire anomalies:

Total metallic rope cross-sectional area (A) was assumed to be 1.21992 in^2.

Metallic cross-sectional area of one 0.080 in. diameter 'calibration' wire was some 0.005027 in^2. Consequently, along rope segment 'δ' the calculated metallic-area increase is 0.412%, and along 'ϵ' it is 1.236%. The corresponding chart-readings in Figures 4 and 6 are closely in line with these values.

(2) At the 'cross-over' point anomalies:

As before, 'A' was 1.21992 in^2, with the metallic cross-sectional area of one 0.082 in. diameter crown-wire some 0.005281 in^2. On flattening these crown-wires, the loss of metallic cross-sectional area (A_{loss}) is:

$$A_{loss} = \left(\frac{D}{2}\right)^2 (\beta - sin\beta\ cos\beta).$$

See Fig. 7 for an explanation of the foregoing symbols.

Consequently, along rope-segment 'α', with 40% of the diameter of a 0.082 in. diameter crown-wire removed by grinding, each such anomaly results in a calculated LMA of some 0.162%. The corresponding LMA values, per flattened wire along rope sections 'β' and 'γ', are 0.085% and 0.023%, respectively. Coincidentally, the magnitude

of the central angle 'β' in Fig. 7 is 78°30'; 60°0'; and 36°52', respectively, for a wire-diameter reduction of 40%; 25% and 10%.

Our chart-readings for the LMA-250 instrument (Fig. 4) are 0.5%; 0.3%; and 0.2%, respectively, for rope-sections 'α'; 'β'; and 'γ'. The corresponding chart-readings for the Magnograph (Fig. 6a) are 0.5%; 0.4%; and 0.3%. Consequently, an average of three (because $0.5\%/0.162\% \approx 3$) flattened crown-wires per cross-section appear to be operative along rope section 'α', and four along section 'β'. The corresponding number along section 'γ' is, however, in the order of 10. We assume, therefore, that the hand-grinder operator's judgement was correct when reducing the wire diameters along sections 'α' and 'β', but that much more than 10% of the crown-wire diameters was ground-off along 'γ'.

ACKNOWLEDGEMENTS

We are grateful to Messrs. G. Delorme, J. Savory, and R. Bole, of Wire Rope Industries Ltd., for their valuable assistance with the design work of our test-ropes, and for the special care they took in manufacturing these non-standard ropes.

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APPENDIX

Figures 1 through 7, inclusive

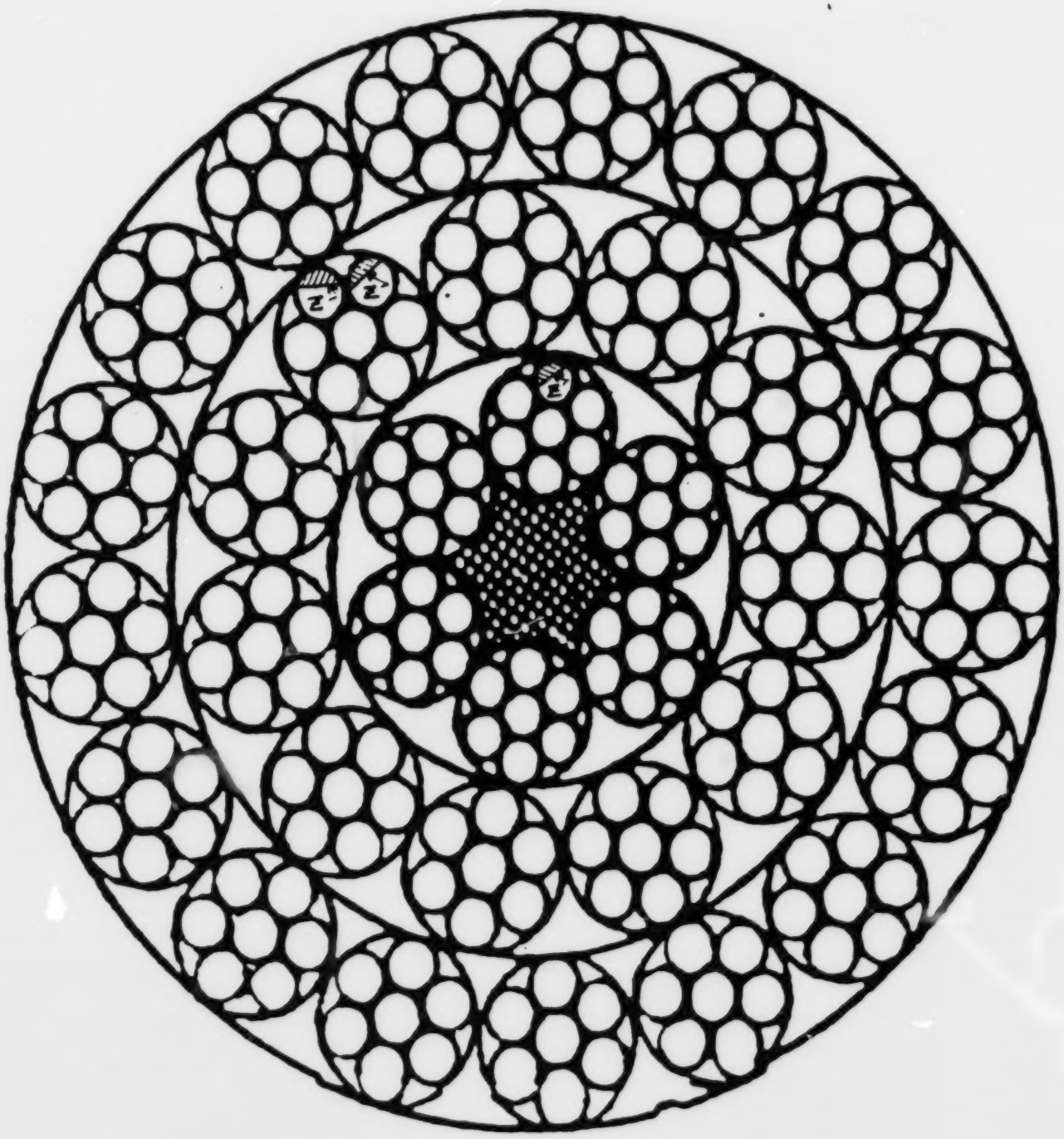
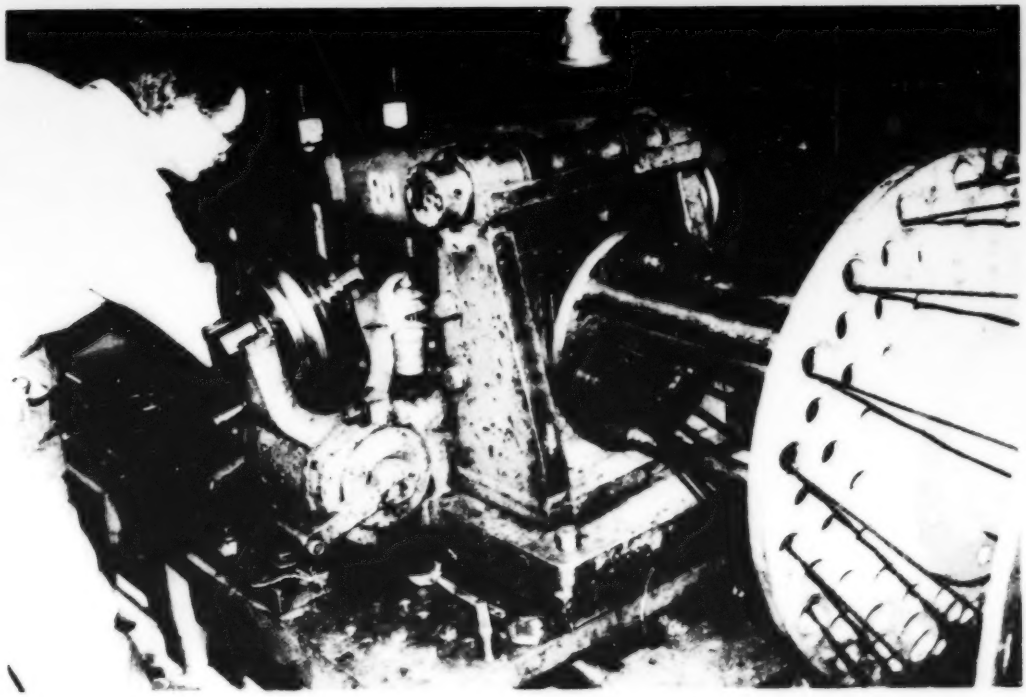


Fig. 1 — Schematic cross section of ropes 'C' and 'D', with artificial anomalies 'Z'

(a)



(b)

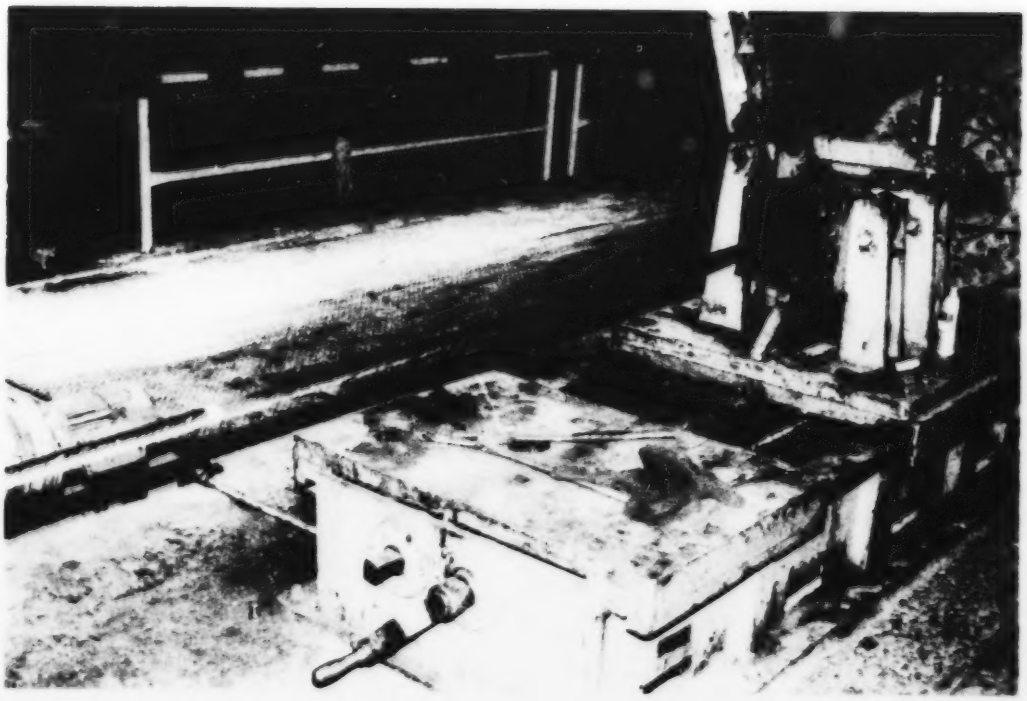
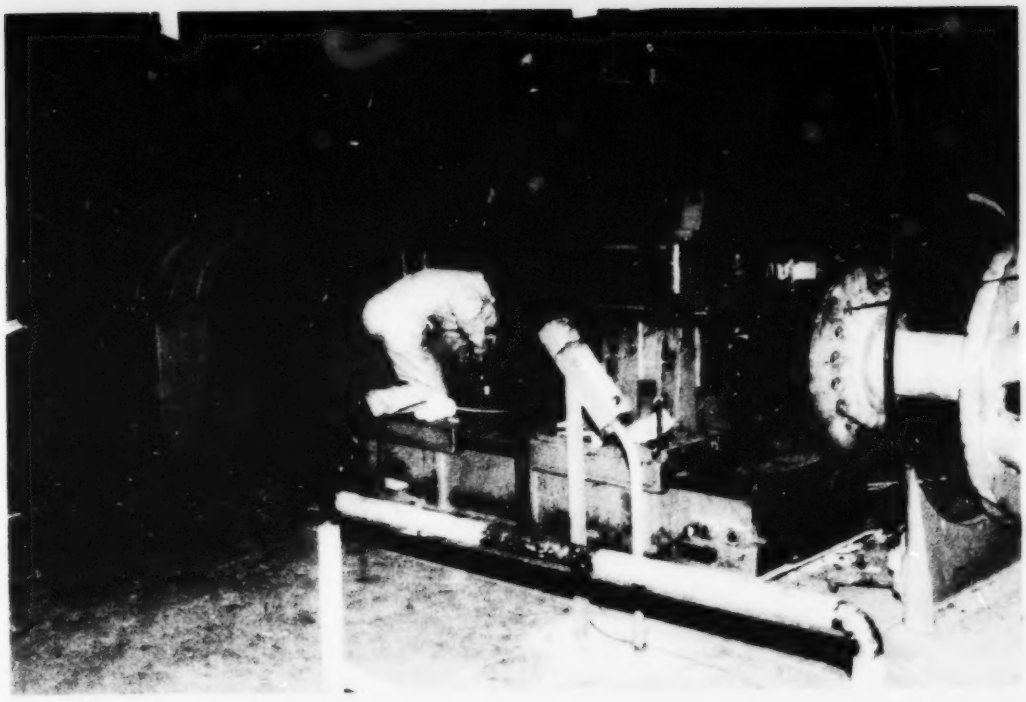


Fig. 2 — Rope preparation; (a) and (b): delineating sections with artificial anomalies

(c)



(d)

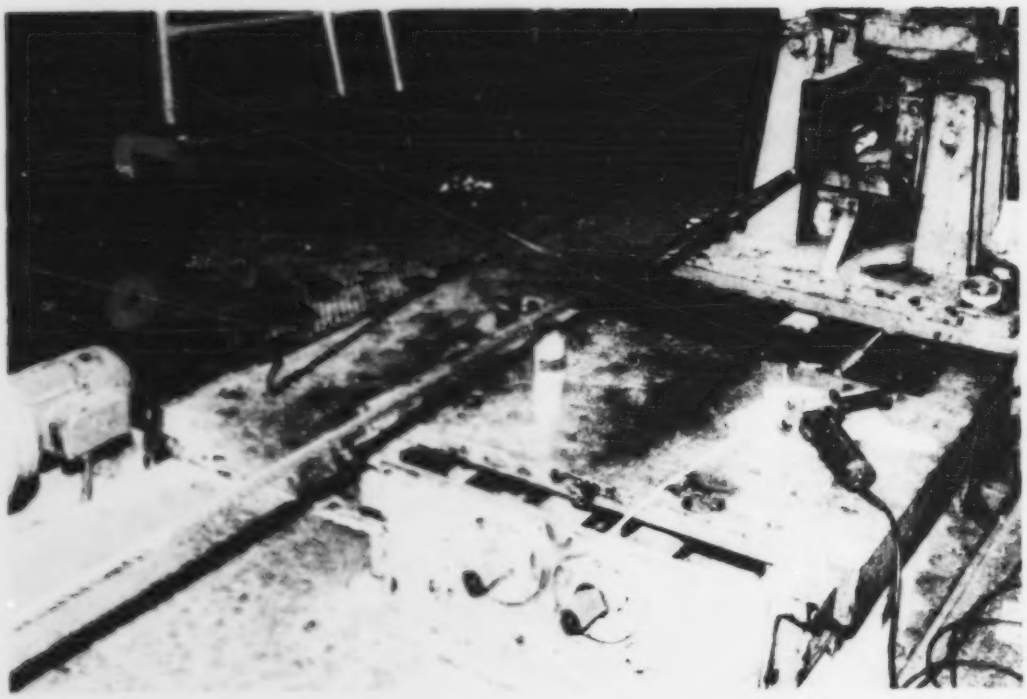
Fig. 2 (continued) — Rope preparation; (c) and (d): introducing anomalies with hand-held grinder

(e)

(f)

Fig. 2 (continued) — Rope preparation: (e) and (f): introducing anomalies with hand-held grinder

(g)



(h)

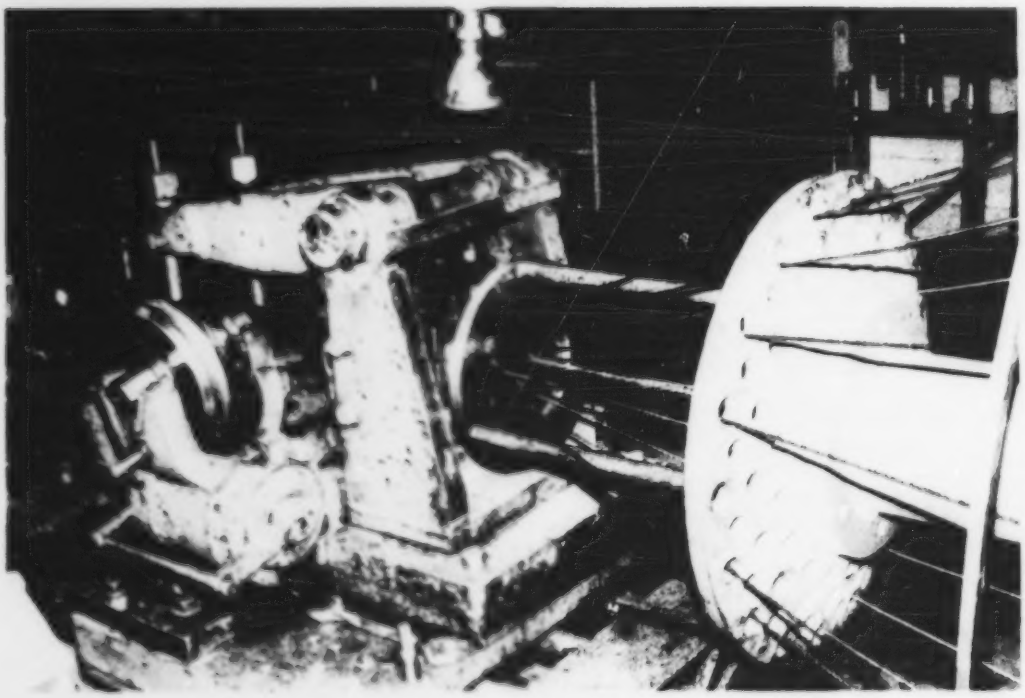
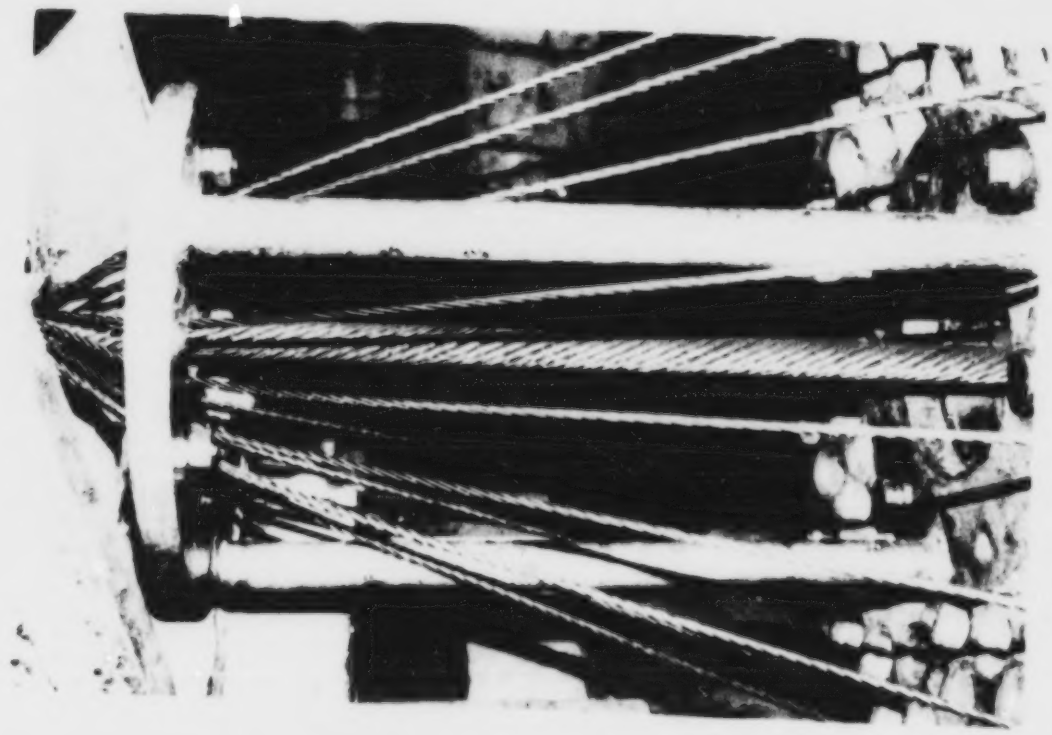


Fig. 2 (continued) — Rope preparation; (g) rope-layer with a completed 6-ft length with anomalies, and (h) closing of rope 'C'

(i)



(j)

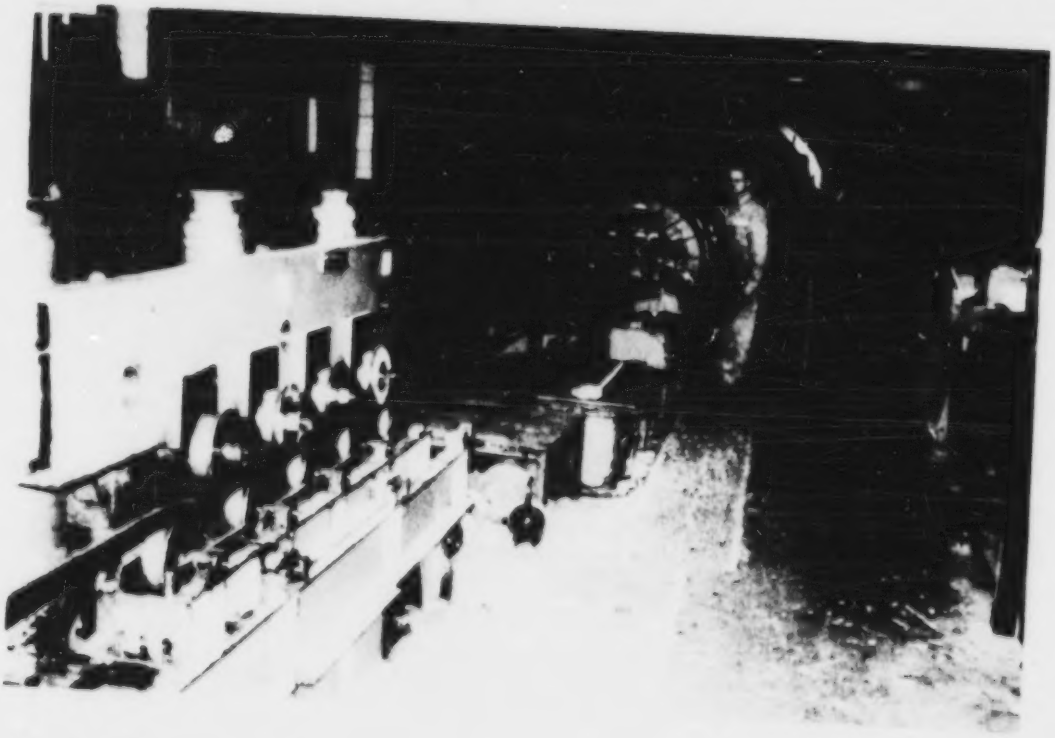
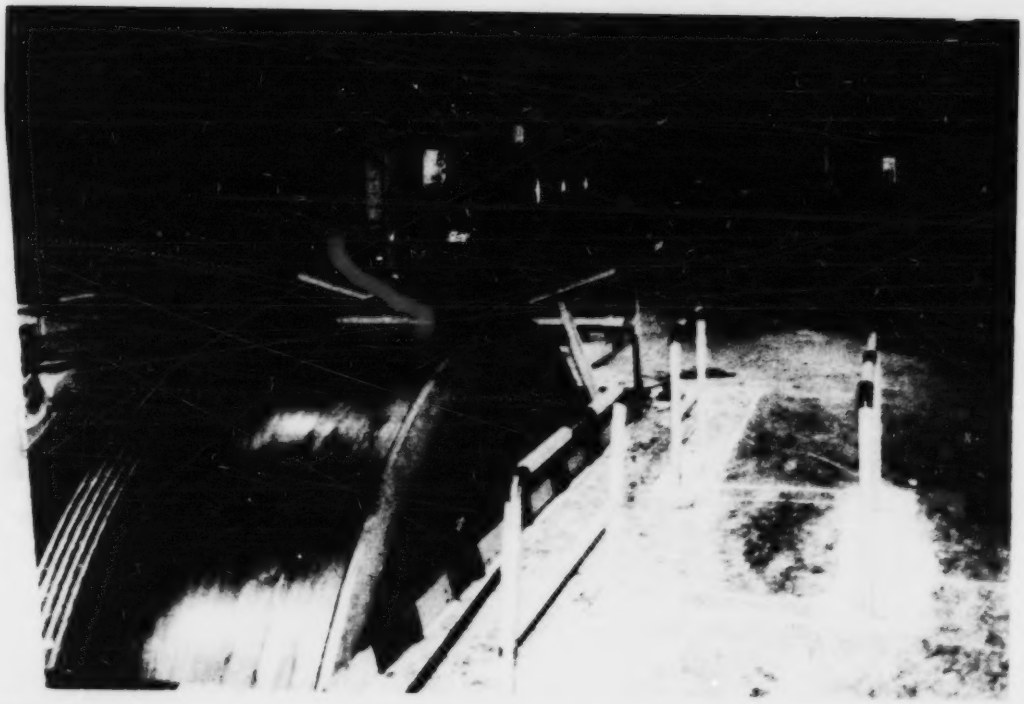


Fig. 2 (continued) — Rope preparation; (i) closing of rope 'D', and (j) completion of manufacturing process

(k)



(l)

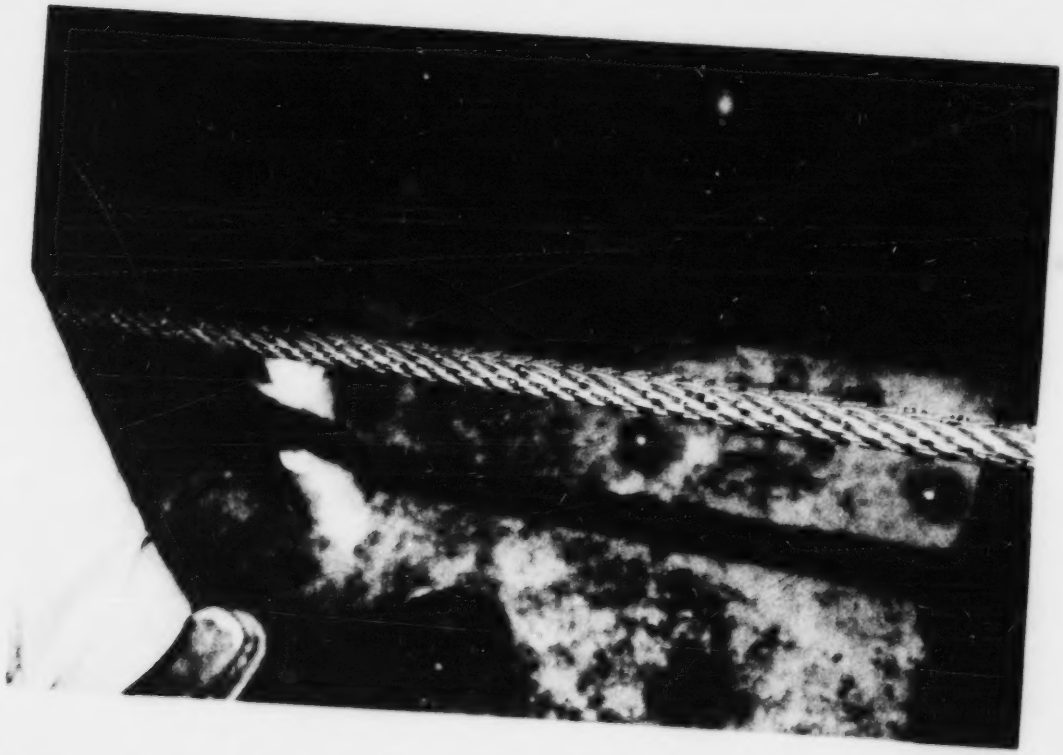
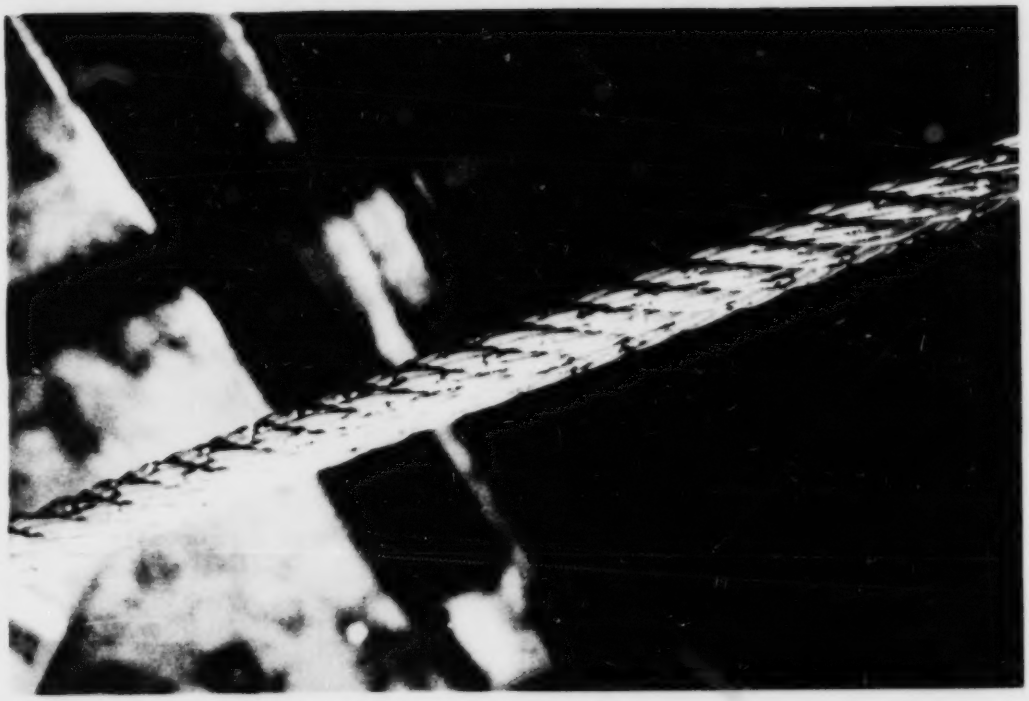


Fig. 2 (continued) — Rope preparation: (k) winding of 500-ft test rope, and (l) close-up view of artificial anomalies along a 6-ft layer-length

(m)



(n)

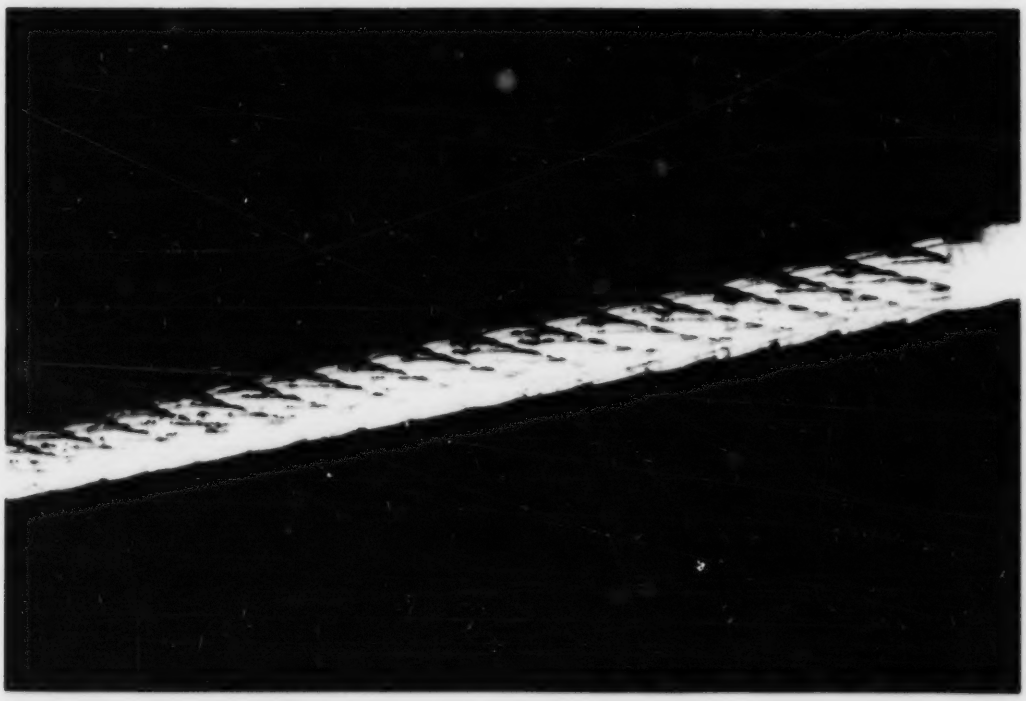


Fig. 2 (continued) — Rope preparation; (m) and (n): close-up view of artificial anomalies along a 6-ft layer-length

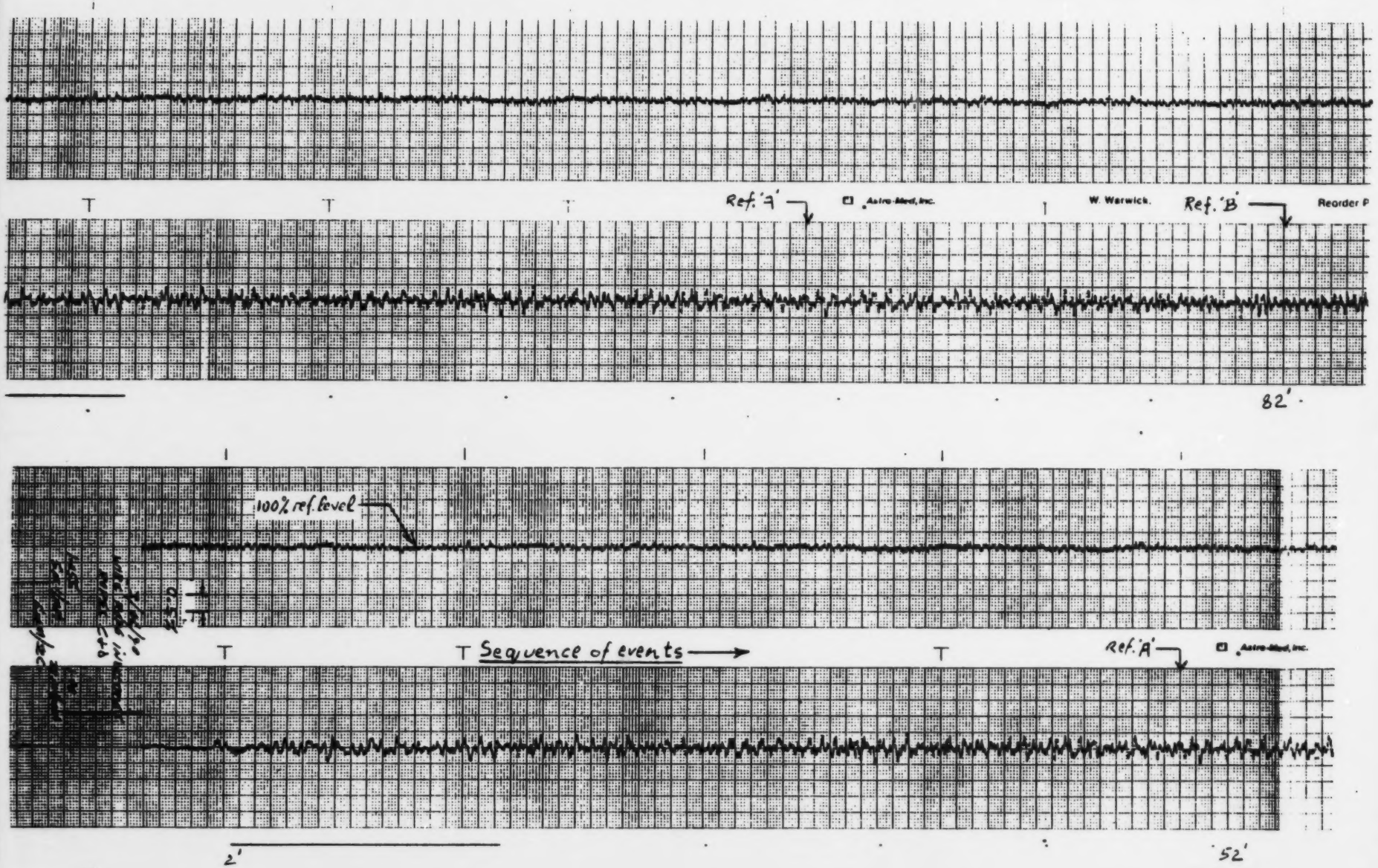


Fig. 3 — Test-chart of rope 'C', obtained with the LMA-250 on 1990 03 06

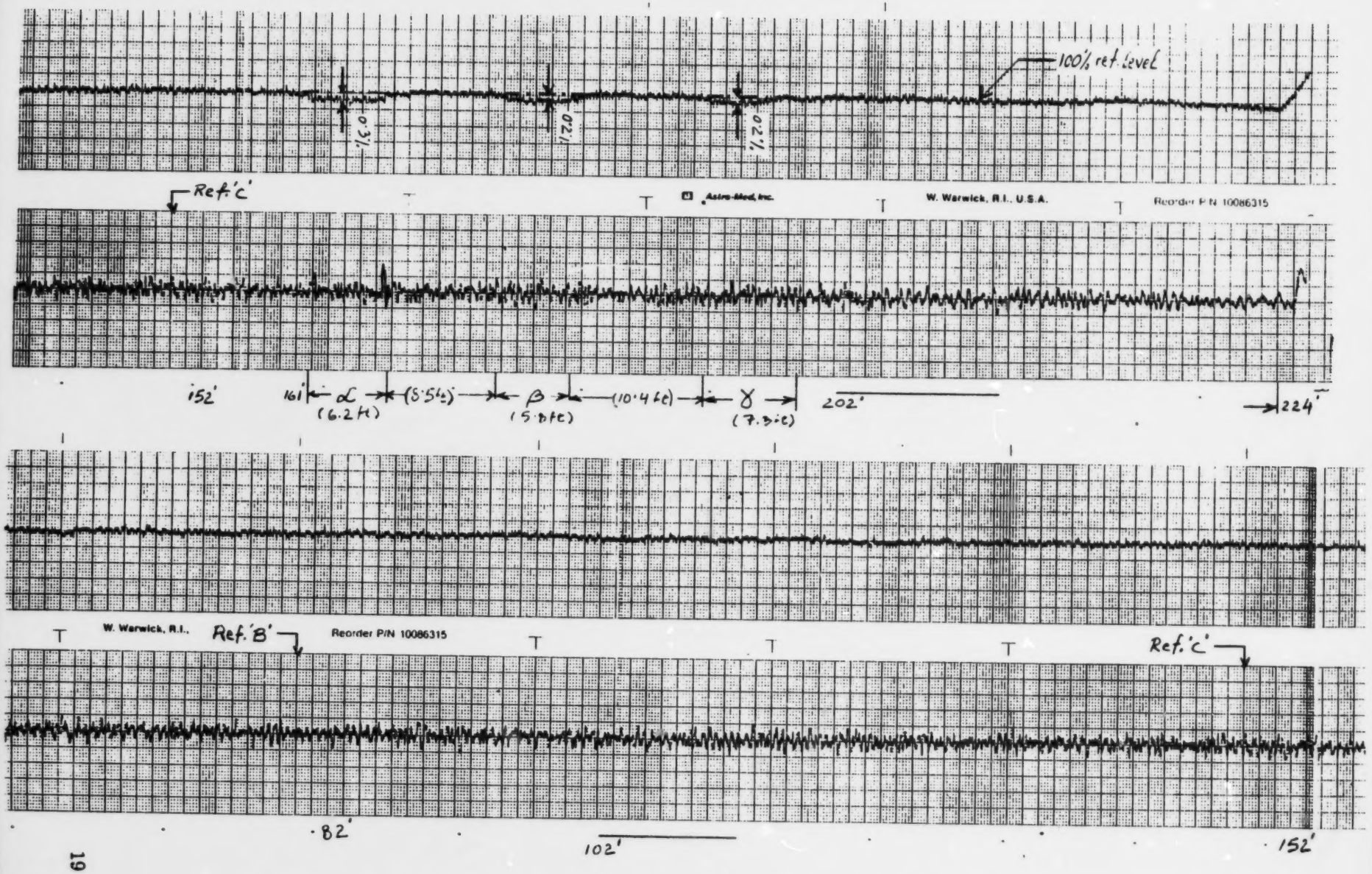


Fig. 3 (continued) – Test-chart of rope 'C', obtained with the LMA-250 on 1990 03 06

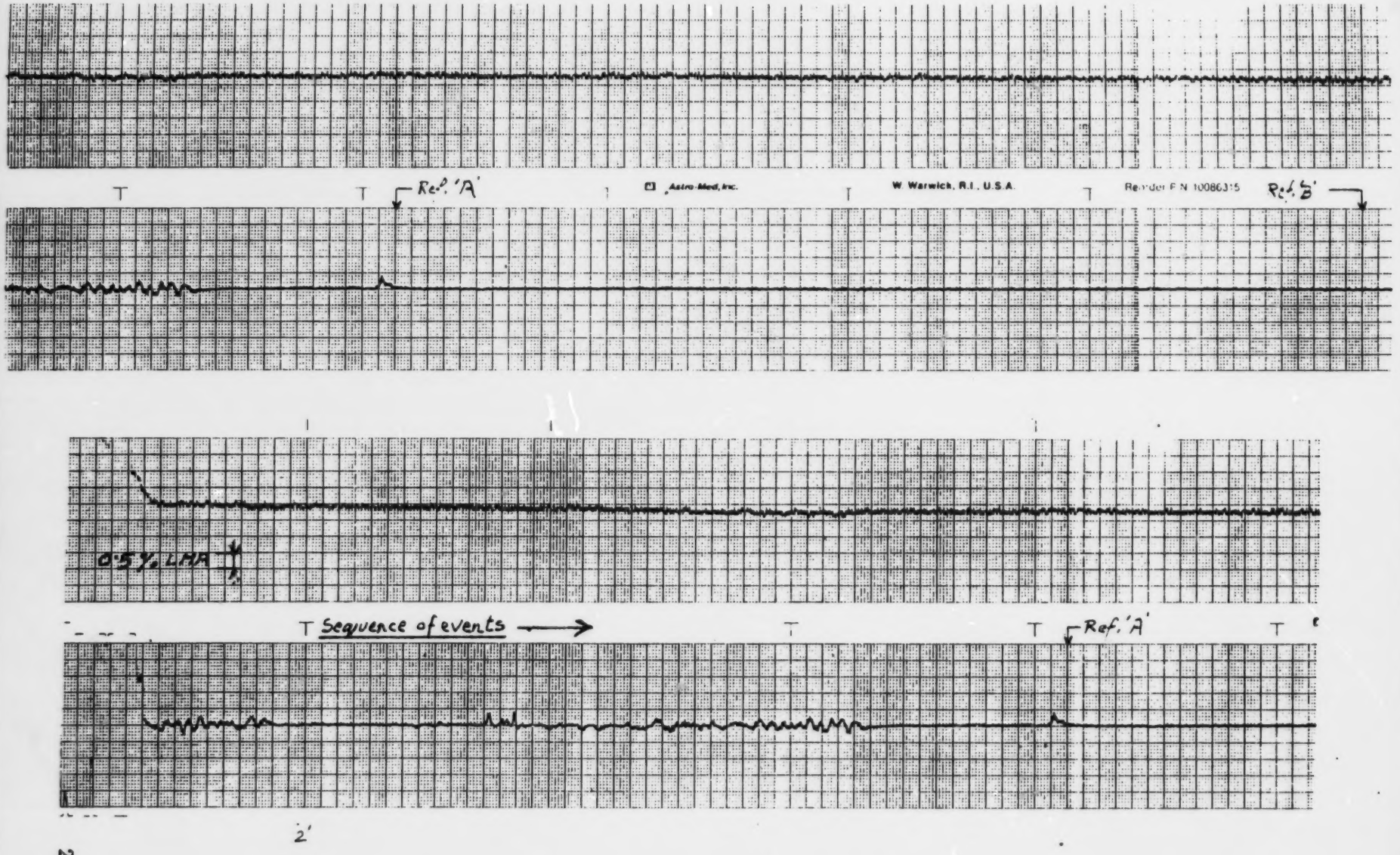


Fig. 4 — Test-chart of rope 'D', obtained with the LMA-250 on 1990 03 06

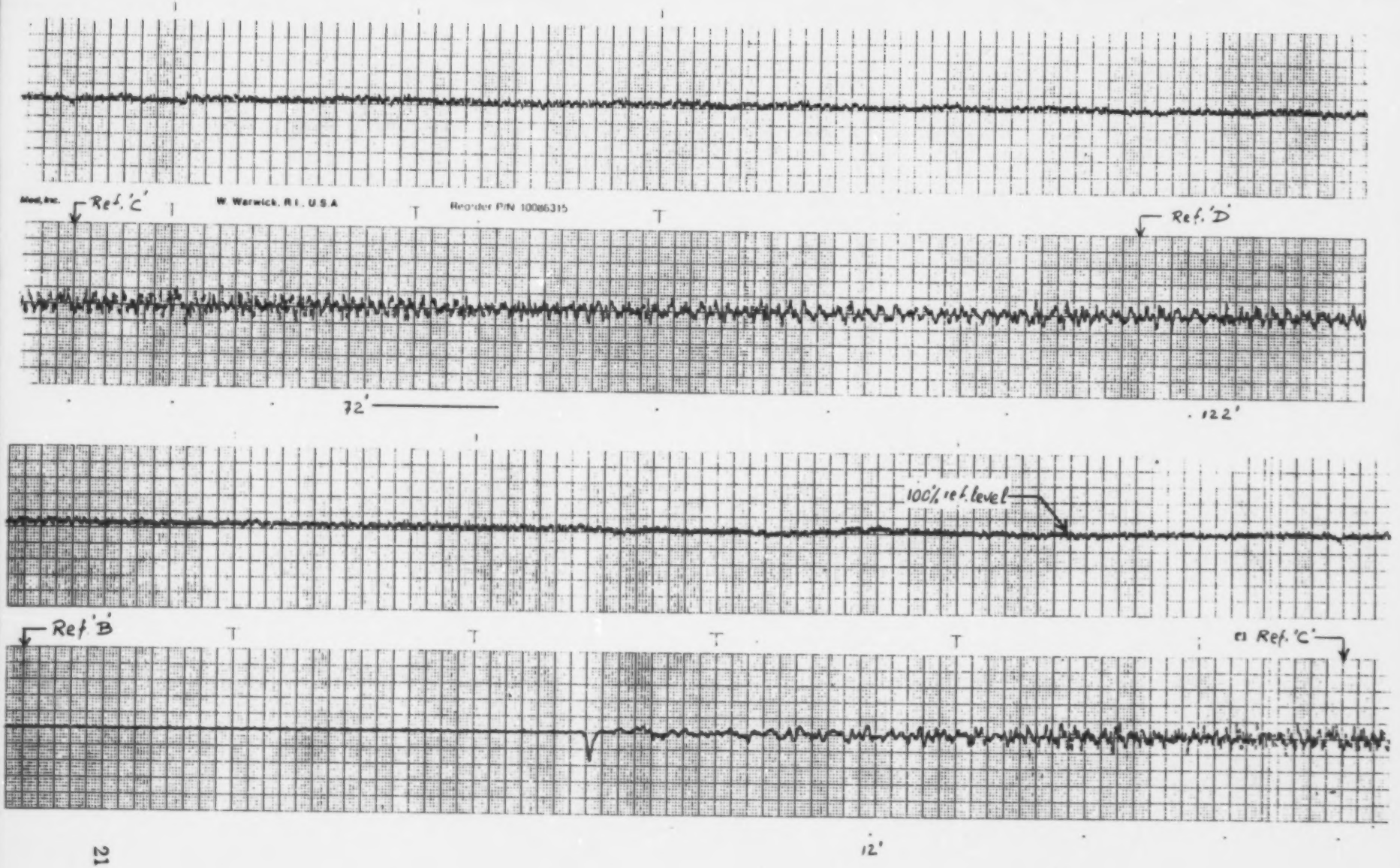


Fig. 4 (continued) — Test-chart of rope 'D', obtained with the LMA-250 on 1990 03 06

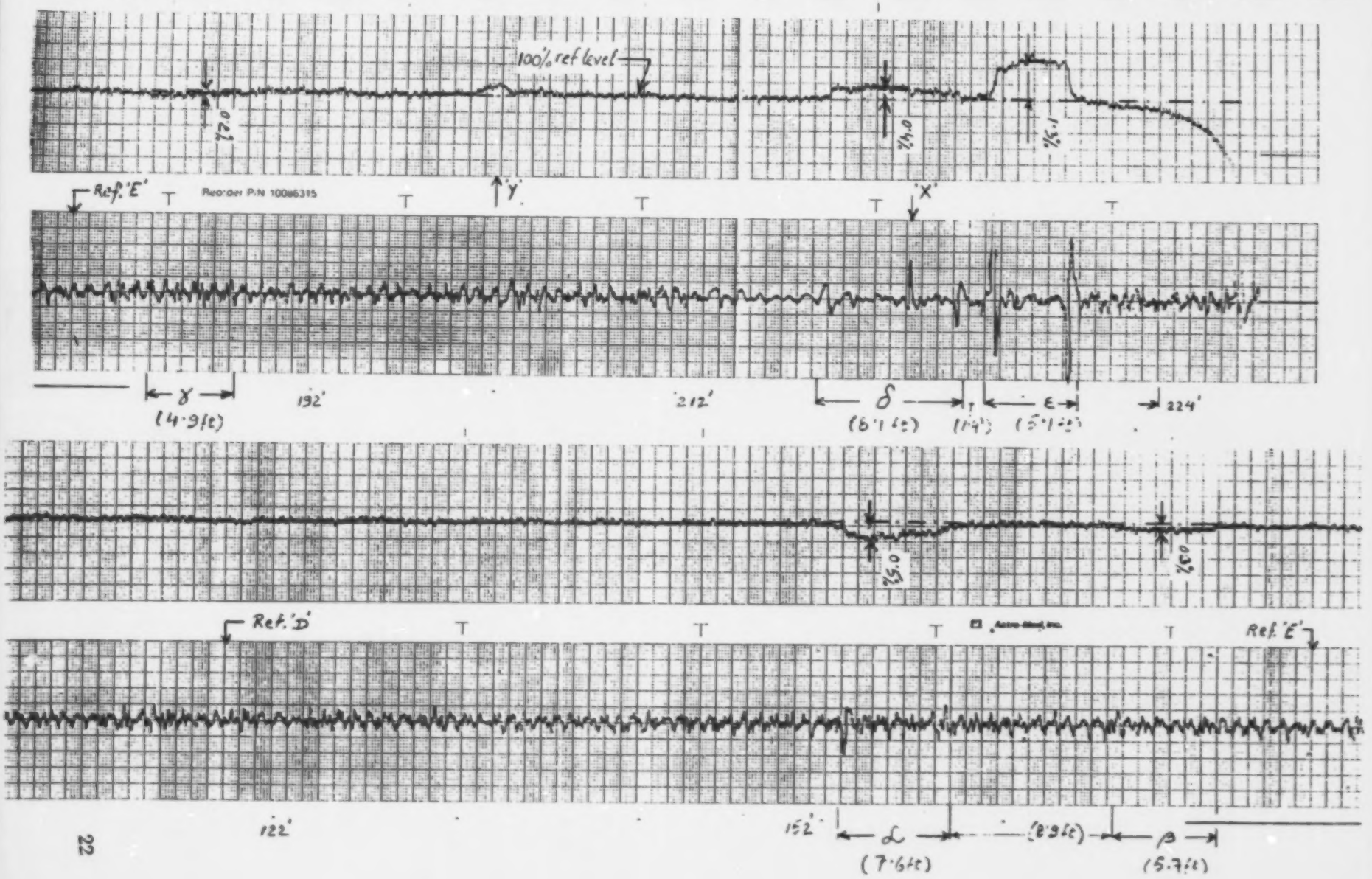


Fig. 4 (continued) Test-chart of rope 'D', obtained with the LMA-250 on 1990 03 06

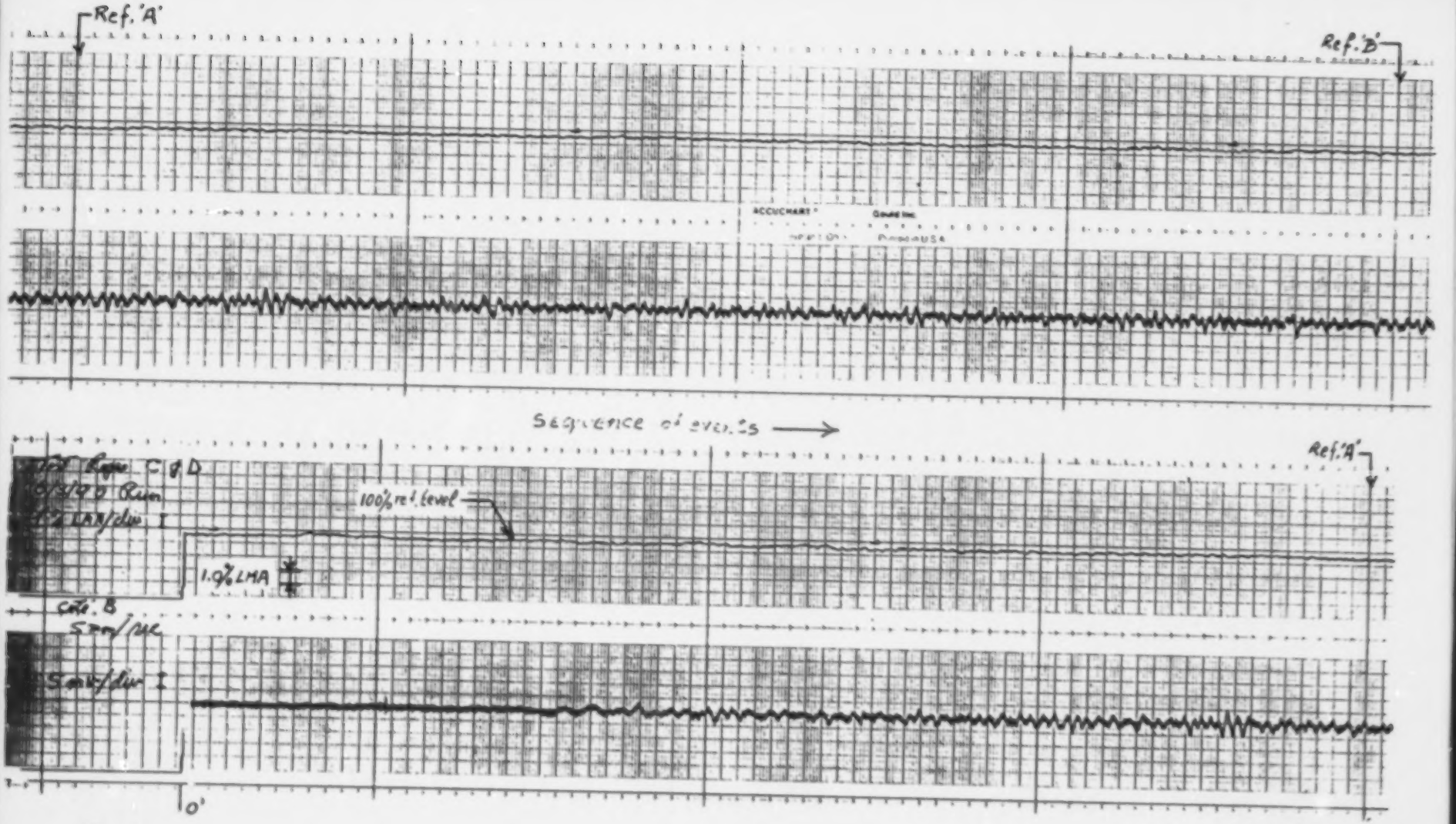


Fig. 5a — Test-chart of rope 'C', obtained with the Magnograph on 1990 03 06: 1.0% LMA per major chart-division

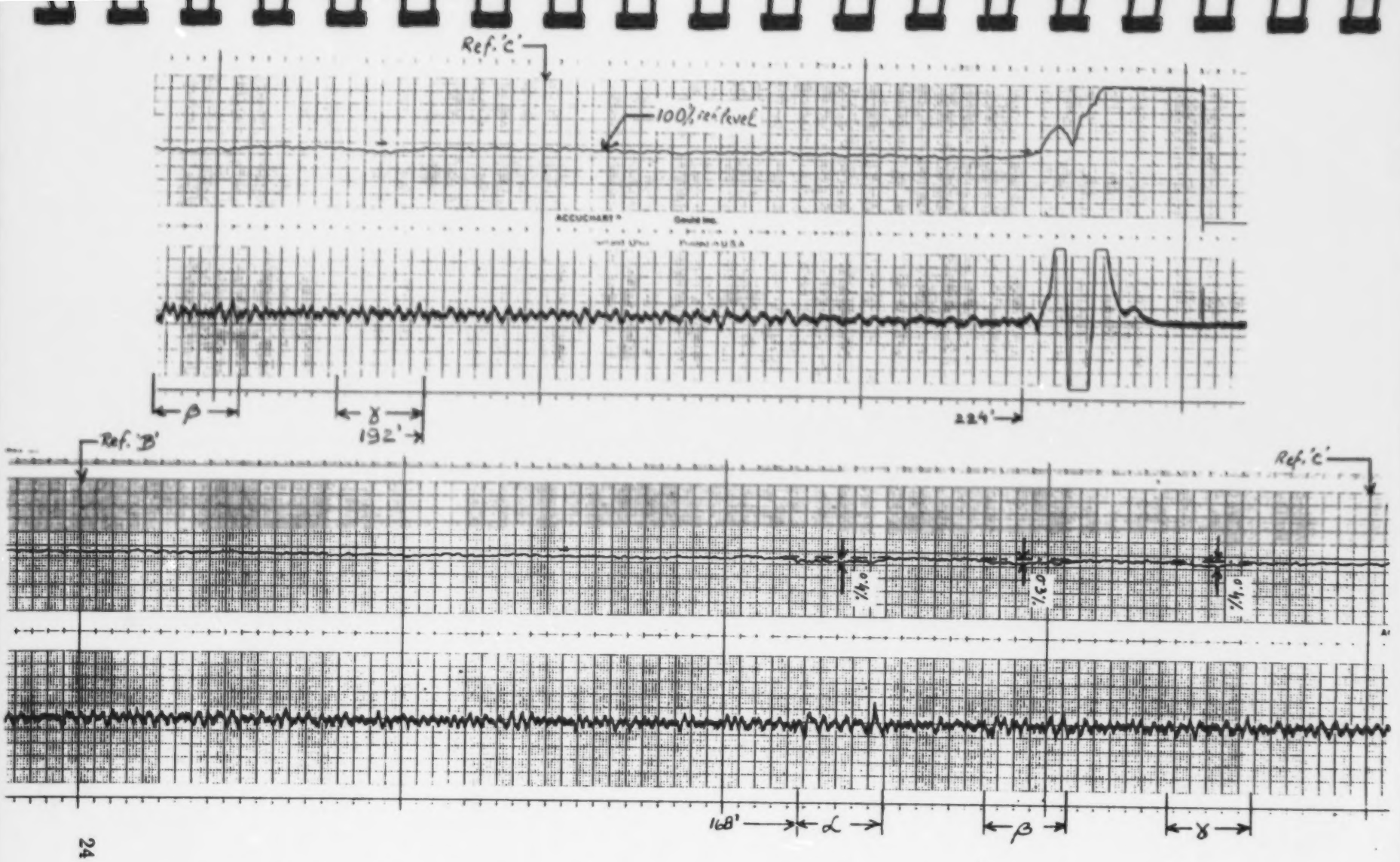


Fig. 5a (continued) — Test-chart of rope 'C', obtained with the Magnograph on 1990 03 06: 1.0% LMA per major chart-division

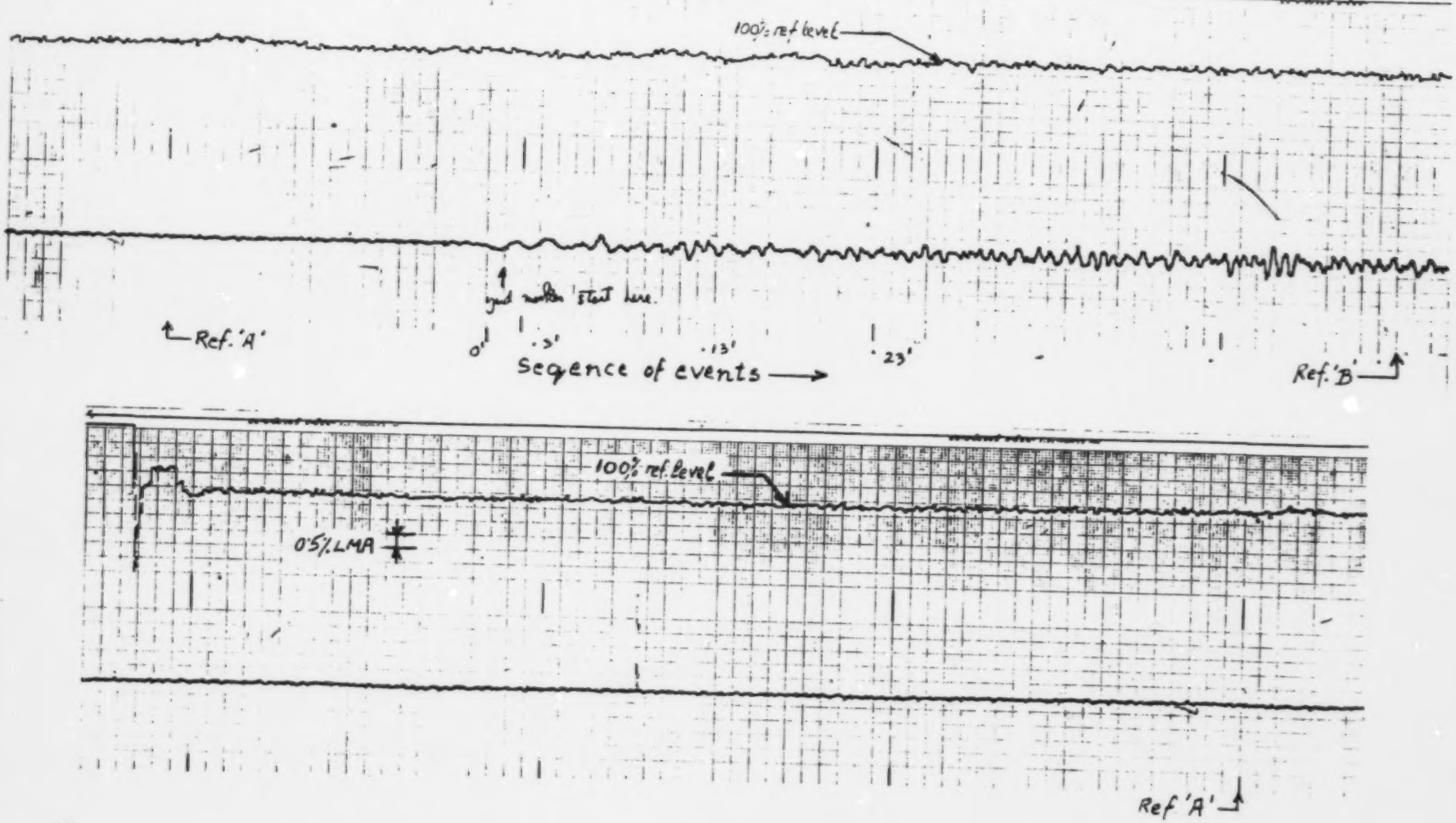


Fig. 5b — Test-chart of rope 'C', obtained with the Magnograph on 1990 03 06: 0.5% LMA per major chart-division

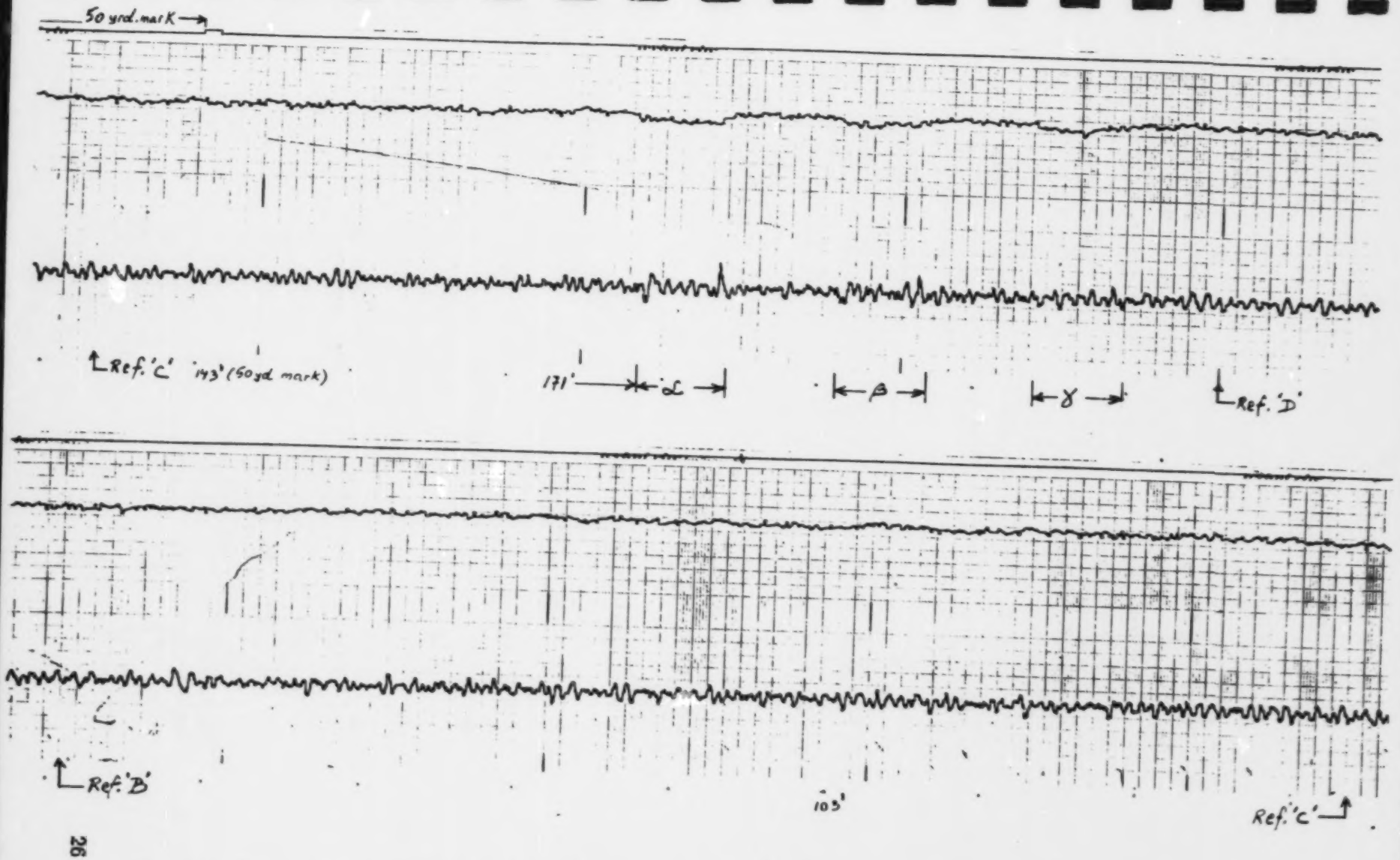


Fig. 5b (continued) — Test-chart of rope 'C', obtained with the Magnograph on 1990 03 06: 0.5% LMA per major chart-division

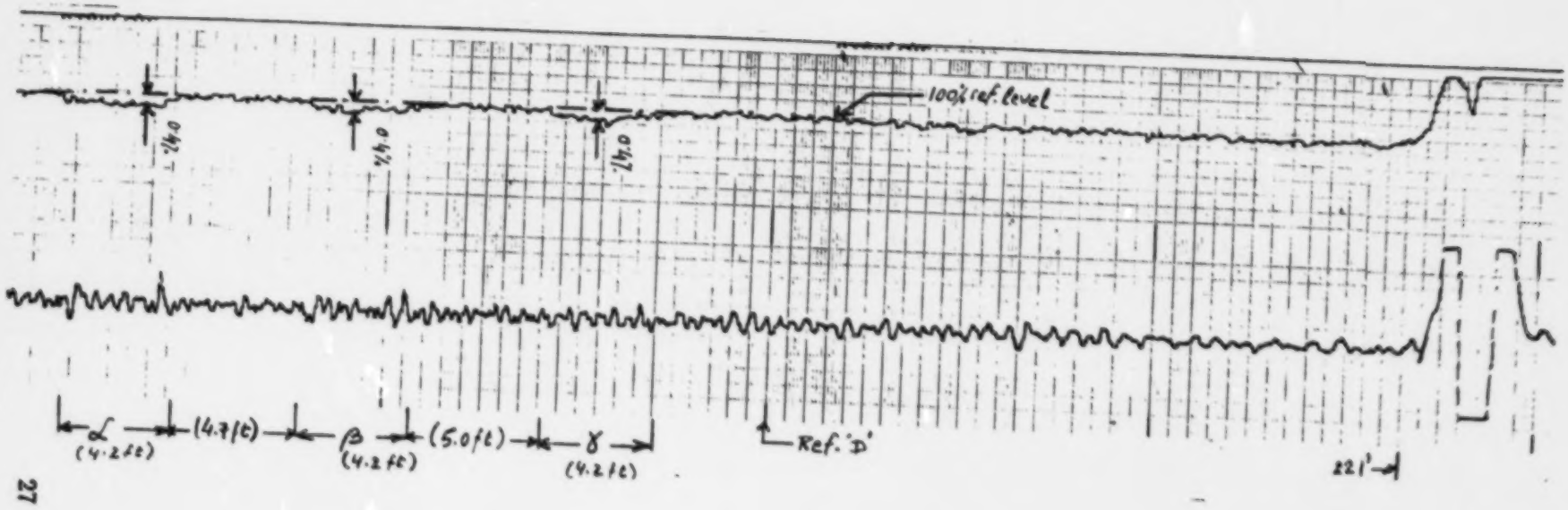


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Fig. 5b (continued) — Test-chart of rope 'C', obtained with the Magnograph on 1990 03 06: 0.5% LMA per major chart-division

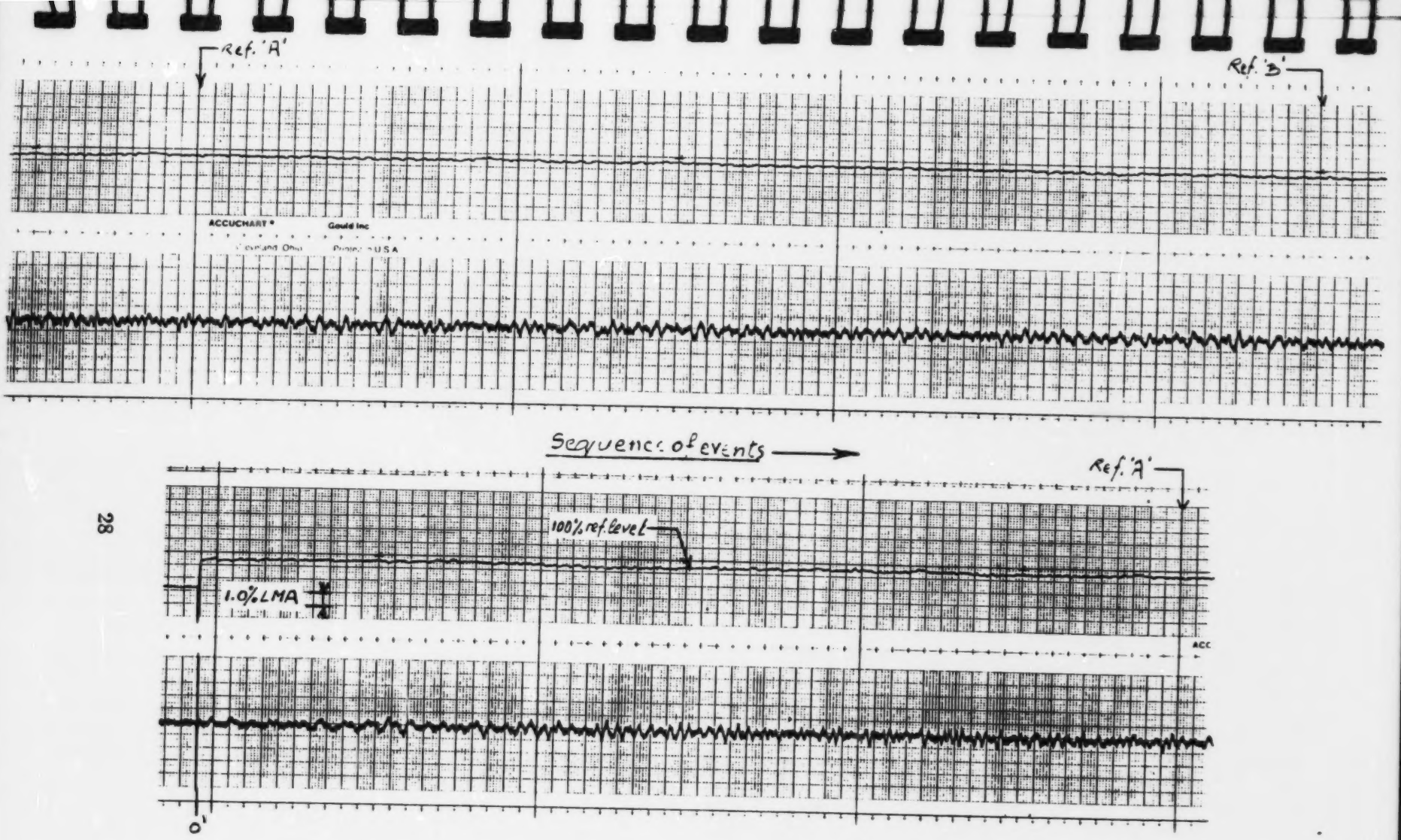

Fig. 6a — Test-chart of rope 'D', obtained with the Magnograph on 1990 03 06: 1.0% LMA per major chart-division

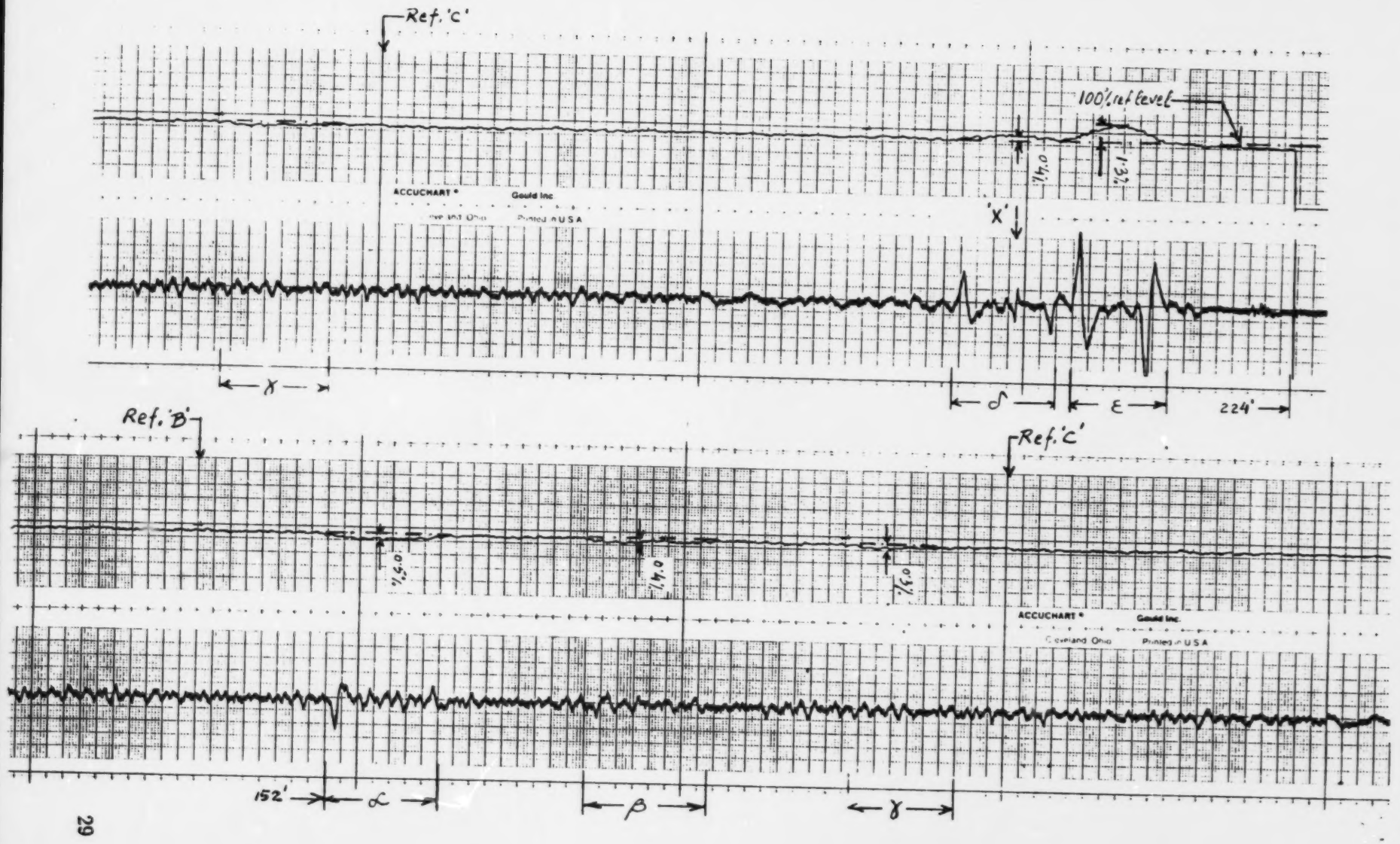

Fig. 6a (continued) — Test-chart of rope 'D', obtained with the Magnograph on 1990 03 06: 1.0% LMA per major chart-division

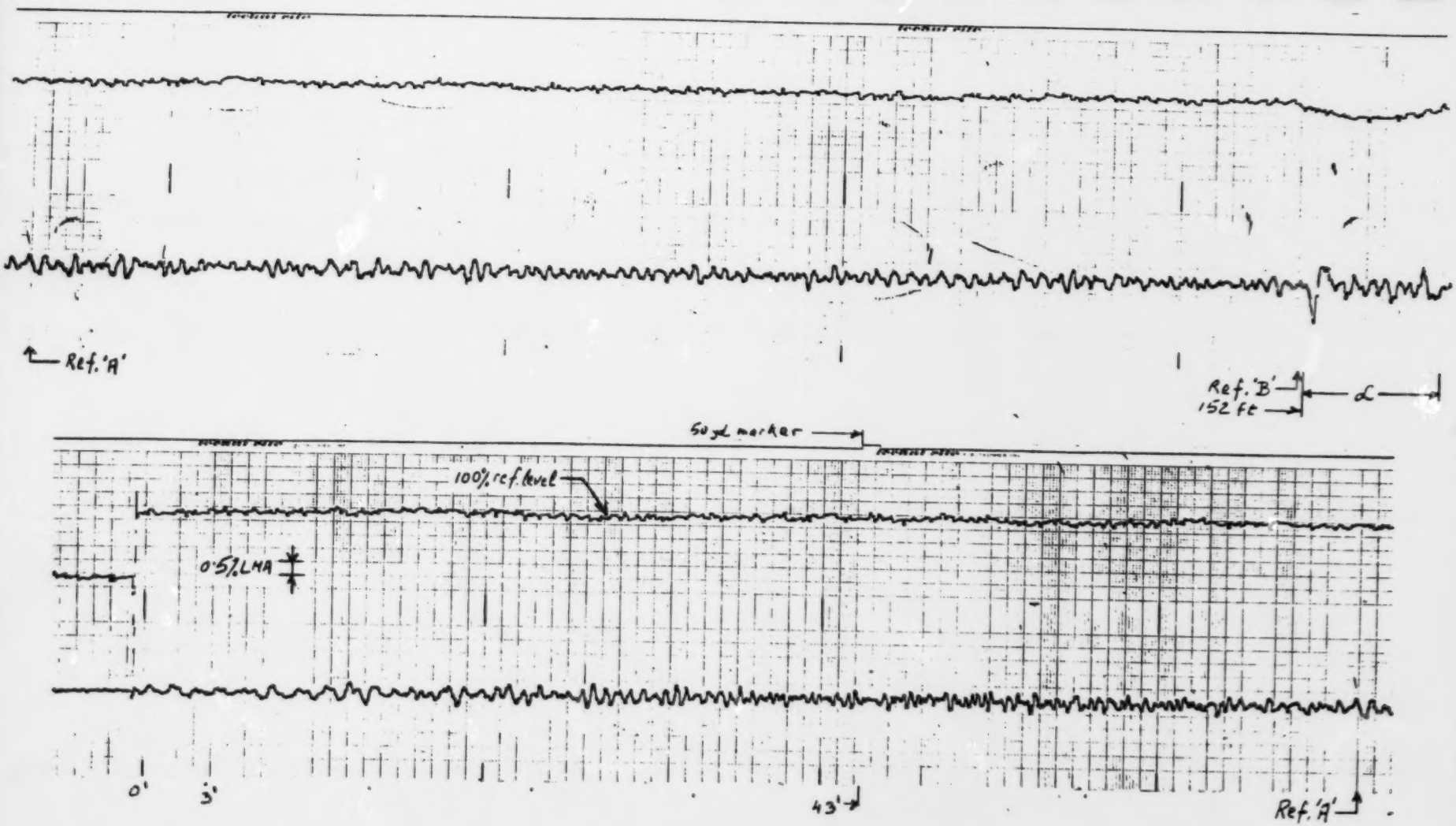

Fig. 6b — Test-chart of rope 'D', obtained with the Magnograph on 1990 03 06: 0.5% LMA per major chart-division

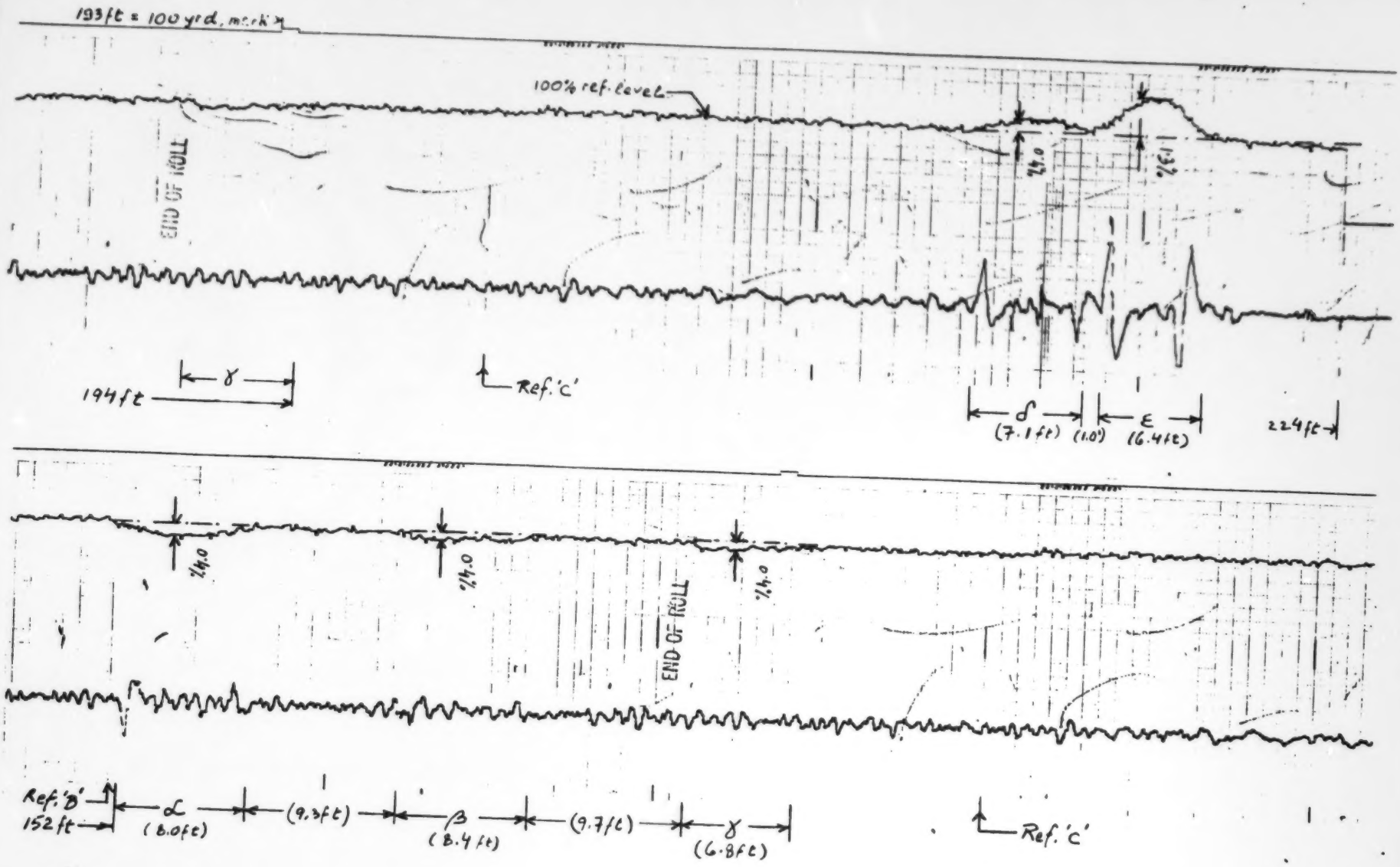

Fig. 6b (continued) — Test-chart of rope 'D', obtained with the Magnograph on 1990 03 06: 0.5% LMA per major chart-division

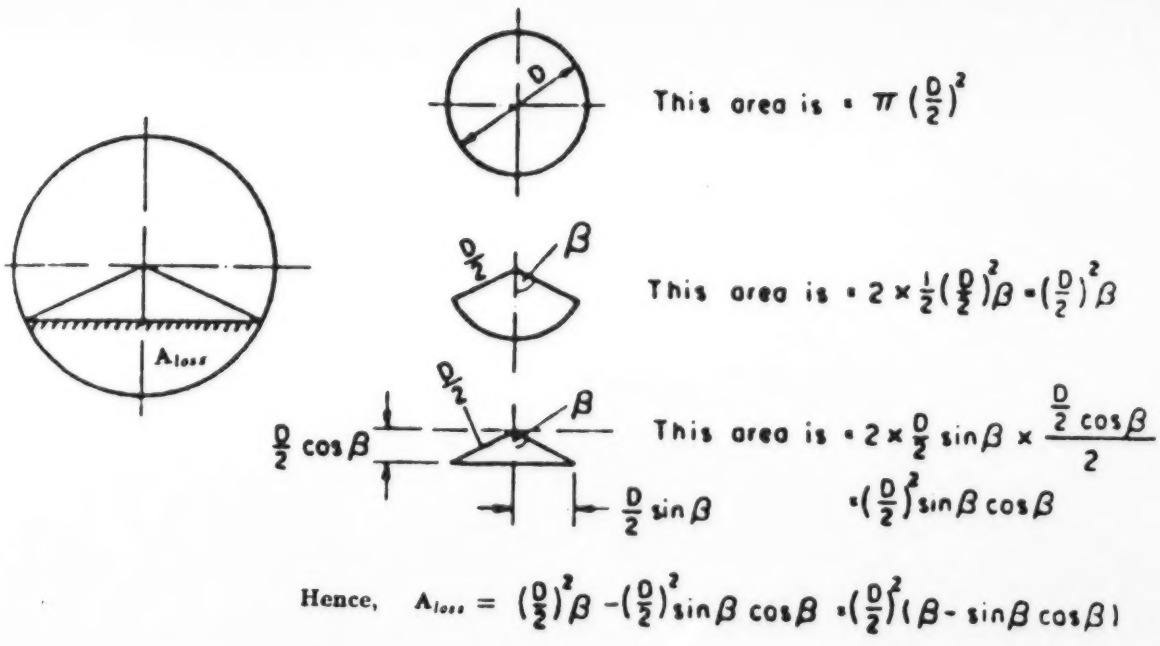
D
This area is = $\pi \left(\frac{D}{2}\right)^2$
$\frac{D}{2}$
β
This area is = $2 \times \frac{1}{2}\left(\frac{D}{2}\right)^2\beta = \left(\frac{D}{2}\right)^2\beta$
A_{loss}
$\frac{D}{2}\cos\beta$
$\frac{D}{2}\sin\beta$
This area is = $2 \times \frac{D}{2}\sin\beta \times \frac{\frac{D}{2}\cos\beta}{2}$
$= \left(\frac{D}{2}\right)^2 \sin\beta\cos\beta$
Hence, $A_{loss} = \left(\frac{D}{2}\right)^2\beta - \left(\frac{D}{2}\right)^2 \sin\beta\cos\beta = \left(\frac{D}{2}\right)^2(\beta - \sin\beta\cos\beta)$

Fig. 7 — Schematic illustration of calculation of area A_{loss}